Arumbera Sandstone truncation, halo and dip closure plays in the southern Amadeus Basin.

(CTP Technical Note 151208)

Introduction

A re-examination of archived and recent data in the southern Amadeus Basin has emphasized the interpretation of a number of novel, large and widespread play types at Arumbera Sandstone level. These include several leads and prospects ready to drill with UGIIP of up to 0.5 TCFG and UOIIP of over 400 MMbbls in the Magee and Maryvale areas in EP 82, where Central Petroleum Limited is in a Joint Venture with He Nuclear Limited. There is evidence of very good sealing qualities above the Arumbera Sandstone in the overlying Chandler Formation Salt; mature source and bottom seal shales occur in the underlying Pertatataka Formation and a variety of trapping mechanisms occur as truncation, halo and dip closure play types. Reservoir potential lies in the Arumbera Sandstone with previously drilled porosities of up to 12%, nominally sufficient to provide production from gas and condensate charged sandstones.

The Amadeus Basin hosts two producing fields, the Mereenie and Palm Valley oil and gas fields and is regarded as being underexplored with an exploration well density of less than 1 well per 5,000 km^2 to date.

There are remarkable parallels in the geology of the Amadeus Basin and other older basins such as the Sichuan Basin in China, the eastern Siberian Platform and Oman where giant oil and gas fields have been discovered.

There are two significant salt horizons in the Amadeus, the Chandler Formation Salt and the Gillen Member of the Bitter Springs Group. Similar salt horizons have acted to trap much petroleum globally but have been largely ignored to date in the Amadeus Basin.

Central has been amassing data over the Amadeus, including modern multifold 2D seismic and has been re-examining novel play types overlooked by previous explorers who have focussed almost exclusively on 4 way dip closures likely to host Ordovician petroleum accumulations. This fresh perspective negates earlier geological dogma and opens up a swathe of new exploration possibilities in the sparsely explored southern Amadeus Basin.

Arumbera Sandstone:

The Arumbera Sandstone is the basal unit of the Pertaoorrta Group which was deposited during a phase of crustal extension and thermo-tectonic subsidence commencing at about 600-580 Ma. The basal unit is the Arumbera Sandstone which is divided into two sequences by Kennard and Lindsay (1991) and Lindsay (1993); the following discussion draws heavily on their work. An unconformity separating Sequences 1 and 2 appears to mark the Cambrian/Proterozoic boundary and in places is denoted by folding, uplift and erosion associated with a late phase of the Petermann Ranges Orogeny (eg in the Magee area). In addition, within the Missionary Plains Trough there is an erosional contact between Sequences 1 and 2 (Lindsay,1987). The main phase of the Petermann Ranges Orogeny corresponds to the base of the Arumbera Sandstone (ie base Sequence 1) although the lower contact with the Pertatataka Formation is conformable in most sub-basins.

Arumbera Sandstone Sequences 1 and 2, which are late Neoproterozoic and Early Cambrian in age respectively, are both mainly fluvio-deltaic in origin and were previously thought to have been concentrated in the northern Amadeus Basin with deposition in three sub-basins; namely the Idirrik Sub-basin in the west, the Missionary Plain Trough and Carmichael Sub-basin in the centre and the Ooraminna Sub-basin to the east. These depocentres and their connecting troughs lose definition southward towards the Central Ridge, which was thought to have been an an effective buttress to major southward progradation of deltaic successions

(Lindsay 1993). However, thin transgressive successions occur in Wallara-1 (90 m) and also Mount Winter-1 (73 m) and East Johnnys Creek-1 (73 m). In addition, reinterpretation of the Erldunda-1 well by this author recognises a 300 m thick Arumbera sequence here and similar, substantial sequences have been recognised on seismic over a wide area of the southerm Amadeus Basin. A particularly good example occurs on seismic line 82-07 where 1300 m of section overlies the Pertatataka Formation with apparent conformity.

The Arumbera Sandstone depositional successions (Sequences 1 and 2) attain maximum thicknesses of 800 m and 500 m respectively in the Carmichael sub-basin, although the thickest section is 2000m northeast of this sub-basin (Weste, 1989). The lower Arumbera Sandstone is the key reservoir in the Dingo and Orange gas fields and is an important gas target in the northern and southern Amadeus Basin although there is also oil potential in some structures eg the Grey Range-Finke anticlinal trend.

The upper Arumbera Sandstone (Sequence 2) is a regressive, shallowing-upward deltaic succession capped by shallow-marine carbonate rocks of the Todd River Dolomite. Differential subsidence occurred during the deposition of the upper Arumbera, Todd River Dolomite and Chandler Formation Salt. However, a basal shale marker at the base of the Giles Creek Dolomite forms a uniform cap rock indicative of preceding peneplanation.

On the southwest margin of the Amadeus Basin, coarse clastic sediments of the Mount Currie Conglomerate were shed northward into the basin from the Musgrave Province as a result of major thrusting associated with the Petermann Orogeny; these probably interfinger with the Arumbera Sandstone but the exact relationship has not been established. To the north, fluvial deltaic progradation into the Carmichael Sub-basin resulted in a major coarsening-upward cycle capped by fluvial and distributary mouth-bar deposits. A mounded facies at the base of the succession may be a lowstand fan (Lindsay 1993).

Chandler Formation :

The Chandler Formation is an Early Cambrian carbonate and evaporite succession, which includes in part organic-rich, foetid, carbonate mudstone which is a potential petroleum source rock. These sediments were deposited during post-Petermann relaxation / extension prior to more regional Cambrian rifting (SRK, 2004). In some areas, the Chandler Formation disconformably overlies the Arumbera Sandstone and a regional depositional model for the unit occurs in Bradshaw (1991). The succession was probably deposited in a shallow-water, deep desiccated basin in three depositional phases: 1) desiccation and evaporite precipitation; 2) basin flooding and carbonate deposition; and 3) karstification and evaporite precipitation. The western end of the basin is envisaged as the distal end of a salt lake.

Recent drilling suggests the succession is probably absent or very thin west of Magee-1 and Mount Winter-1. Deposition was concentrated in the central-eastern portion of the basin in three north–south-trending facies belts (Bradshaw, 1991). In the westernmost belt, the Chandler carbonate facies is dominant, comprising relatively thin (10–50 m), areally extensive, black, foetid carbonate mudstone with siltstone, shale and abundant chert. An anoxic, shallow-water, restricted marine environment of deposition has been interpreted (Bradshaw, 1991). The section thickens eastward to a mixed carbonate/salt facies up to 500 m thick and the salt ranges in thickness from less than 50 m to over 1000 m.

The Chandler Formation evaporites form a major decollement zone which controlled deformation during the multi – phase Alice Springs Orogeny. Extensive salt flowage often occurred into tight anticlinal zones often bound by broad synlines. This style of deformation is similar in part to that affecting the Willouran evaporites of the Gillen Member during earlier orogenic phases.

New Interpretations

The acquisition of new seismic in the Magee area has greatly expanded the extent of the Arumbera Sandstone and overlying Chandler Formation Salt in this area, enhancing the prospectivity of Arumbera dip closure and truncation plays over a wide portion of the southern Amadeus Basin.

1) A new interpretation of tectonic elements suggests the Central Ridge may have acted to some extent as a buttress controlling Arumbera sedimentation but indeed the northwest trending Erldunda Fault Zone was probably a more fundamental influence on the depositional regime.

2) In the southern part of the basin, a 300m thick sequence of Arumbera Sandstone is now interpreted in Erldunda-1, directly overlying Pertatataka Formation. This is the first time this unit has been interpreted in the southern half of the basin, aside from a thin section in Wallara-1, and indicates a much wider regional extent than previously interpreted.

3) Over wide areas of the southern Amadeus Basin, seismic reflectors lying above, and in conformity with the underlying Pertatataka Formation are believed to represent sequences of Arumbera Sandstone. These reflectors often display major truncation associated with uplift and erosion during a late pulse of the Petermann Ranges Orogeny. This is interpreted to correspond to a period of erosion intervening between Arumbera Sequences 1 and 2 in the northern part of the basin, as described by Kennard and Lindsay (1991). This boundary denotes the unconformity between the Late Neoproterozoic (Ediacran) and the Early Cambrian sequences.

Arumbera Sandstone Plays in the southern Amadeus Basin

The Arumbera Sandstone is interpreted on seismic in the Magee area, where it is truncated in part by a late phase of the Petermann Ranges Orogeny. Blanketting the area is the Early Cambrian Chandler salt which provides excellent vertical seal thus probably validating Arumbera truncation, Halo and dip closure plays.

Factors fundamental to the aforementioned Arumbera Sandstone plays are discussed below:

1) A thick gross Arumbera Sandstone section, which in Erldunda-1 totals 300m in thickness, provides the reservoir component of the play. Halotectonics (developed in the underlying Gillen Member Salt) drives significant thickness variations within the unit as does differential erosion at the base Cambrian unconformity.

2) The presence below the Arumbera Sandstone of thick Pertatataka shales, which are believed to be the source of gas accumulated in several Arumbera fields seen to the north (eg Dingo and Orange), provides a proven sourcing scenario. Pertatataka shales underly Arumbera reservoirs on a large scale in the southern Amadeus Basin, and they appear to be largely conformable units. The Pertatataka thus provides ideal vertical juxtaposition of source and basal seal with overlying reservoir facies, in turn blanketed by Chandler salt top seal.

In summary, all the required parameters for these plays are in place: mature source rocks (Pertatataka Formation), viable reservoir sandstones (Arumbera Sandstone), Top seal (Chandler Formation Salt), and base seal (Pertatataka Formation). The maximium thickness of Arumbera Sandstone is best quantified by assuming a base Arumbera pick occurs immediately downdip of the “bald” Magee well. The Arumbera Sandstone sequence is variably eroded at the main truncation surface and is thin or absent over the main structural closures at Magee and Maryvale but down dip the Arumbera could be up to 250 ms thick (600 m).

Maturation of Source Rock Facies

Maturation data from widely spaced wells in the southern Amadeus Basin reveals high maturities at relatively shallow present day depths, indicating major basin unroofing on a regional scale. This is indicated in Young and Ambrose (2007) who noted that in Murphy-1 nearly 2200 m of section was eroded during the Petermann Ranges Orogeny. The main source intervals are the Gillen Member (Bitter Springs Formation-Willouran), Aralka Formation (Sturtian) and Pertatataka Formation (Marinoan). Source rock maturation data, based mainly on the Methyl Phenylthrene Index (MPI) is summarised below .

Well	Stratigraphy	Depth (kb)	VRo
Magee-1	Gillen Mbr	2335 m	1.02
Mt. Charlotte-1	Upper Bitter Springs	1600 m	0.92
Murphy-1	Aralka Fm	1056 m	2.00
Erldunda-1	Pertatataka Fm	1274 m	0.90
Wallara-1	Aralka Fm	~1290 m	1.05
Wallara-1	Bitter Springs Fm	~ 1450 m	0.97

In Magee-1, 7 shale samples from the Gillen Mbr yielded relatively low TOC's <1% but Tmax data indicated all samples were in the mid-late oil window which matches the VRo data listed above and is also consistent with Production Indice (S1/S1+S2) values of between 0.2-0.32. Considering the strata on seismic data show some deepening away from the structural highs it is concluded slightly higher maturites would exist in these areas at the Gillen level and at the level of the Pertatataka Formation.

The synrift Pertatataka Formation is a proven gas source rock in the northern part of the basin (eg Dingo field) where it is usually disconformable on the Areyonga Formation or Pioneer Sandstone. Despite a relatively low organic carbon content (probably due to maturation loss), recent studies of source rock extracts and gas samples indicate this unit has sourced the gas at Dingo Field (C. Boreham pers.com.).

The Pertatataka Formation may also be an important regional oil source rock which has been underestimated in the past, particularly in the southern Amadeus Basin. Importantly, liquid petroleum was recorded in stratigraphic drillhole BRD05DD01 in the southwestern Amadeus Basin. This petroleum sample and the sedimentary bitumen share several very unusual characteristics including acyclic isoprenoids >C20 which were unusually abundant and included C40 cartenoids (J. Brocks pers.com, Ambrose and Young,2006). Also present in both samples were unusual diahopanes and farrihopanes. These unusual geochemical signatures correlate well with source rock /oil analyses from producing Neoproterozoic basins in Oman and Siberia and confirm the Pertatataka Fm. as a potential oil source rock on a regional scale.

Hydrocarbon Prospectivity

In the general area surrounding Magee-1, several new prospects have evolved as a result of applying this new stratigraphic regime and also the acquisition of additional seismic.

a) Magee Truncation Play (Prospect – Drillable)

The zero edge for the Arumbera Sandstone, as defined where it is truncated by the overlying Chandler Fm salt, can be mapped along the northern margin of the Magee structure as defined in Figure x. Structural closure into the zero edge totals ~5 km2.

Two possible locations are suggested:

1) Location A, on line CM08-03/04, would test the both the Magee Truncation play within closure and also the Magee under thrust 4 way dip closure. The latter is attractive as several N-S dip lines (DH91-2N, CBM08-05,07,08) display considerable thickening of the Heavitree Quartzite on the underthrust sheet whereas the overthrust surface was peneplained prior to deposition of relatively thin Heavitree Quartzite (Dr. Henry Askin, pers. com.).

2) Location B, on line CM08-02, would test the Magee Truncation play within closure and also resolve the downdip extent of the Heavitree Quartzite 4 way dip closure in the overthrust sheet.

b) Maryvale Halo Play (Lead – Incremental seismic required)

This lead is an unusually broad anticlinal structure cored by Gillen Salt. Obvious erosion and truncation of the Arumbera Sandstone and Pertatataka Fm at the base Cambrian unconformity have probably also resulted in erosion of the Arumbera Sandstone from the crest of the structure. The latter thickens markedly down-flank and has all the criteria of a classic Halo play. Chandler Formation Salt blankets the structure forming top seal while base seal and source is provided by the Pertatataka Formation. The lead is defined on two lines but further seimic coverage is required in the critical dip direction to the northwest spill-point.

c) Idracowie High Plays (Lead- Incremental seismic required)

There are two weak leads on the southern flank of the Idracowie High which is a major zone of basement involved thrusting with associated Gillen Member halotectonics. On the southwestern flank of the high (the Chambers lead) the Arumbera Sandstone may seal against a major thrust fault and strata show associated 2 way dip roll into the fault (CM08-14); further potential lies updip of this fault but the play requires incremental seismic to define 4 way dip closure and/or fault seal.

A second Arumbera truncation play (Robinson lead) occurs on the southeastern margin of the high (Line CM-0803/04) where Arumbera sandstone reflectors are truncated against the base Cambrian unconformity being sealed by Chandler Fm salt. The play requires incremental seismic and its veracity would be enhanced by drilling success at one or more of the afore mentioned prospects

Undiscovered Petroleum Initially In Place (UGIIP or UOIIP -_SPE)

Magee Arumbera Truncation Play

Gross Column	255 ft
Net/gross	0.7
Area	8400 acres
Net Pay	179 ft
Porosity	12%
Sh	70%
1/Bg	200
1/Bo	0.9

GF	0.5
Gas Volumetric Factor	43560
Oil Volumetric Factor	7758.

UOIIP	**434 mmbl**
UGIIP	**548 Bcf**

Magee Heavitree Play

Gross Column	30 ft
Net/Gross	0.66
Area	2425 acres
Net Pay	20 ft
Porosity	3% matrix, 1.5% fracture
Sh	70%
1/Bg	200
Geometric Factor	0.4
Gas Volumetric Factor	43560

UGIIP	**5 Bcf**

Magee Underthrust Heavitree Play

Gross Column	525 ft
Net/Gross	0.66
Area	2145 acres
Net Pay	346 ft
Porosity	9%
Sh	70%
1/Bg	200
Geometric Factor	0.6
Gas Volumetric Factor	43560

UGIIP	**245 Bcf**

if matrix and fracture porosity of 4.5% is assumed
UGIIP = 123 Bcf

Maryvale Arumbera Lead (4 way dip/Halo Play)

Gross Column	250 ft
Net/gross	0.7
Area	8800 acres
Net Pay	175 ft
Porosity	12%
Sh	70%
1/Bg	200
1/Bo	0.9
GF	0.5
Gas Volumetric Factor	43560
Oil Volumetric Factor	7758.

UOIIP	**451 Mmbl**
UGIIP	**563 Bcf**

Conclusions

A sedimentary sequence up to 1300 m thick conformably overlies the Pertatataka Formation in the Murphy and Magee areas of the southern Amadeus Basin. The sequence has been intersected in Erldunda-1 where it has been eroded but ~300 m of argillaceous sandstone and minor siltstone were intersected. The presence in the Magee area of a widespread blanket of early Cambrian salt (Chandler Formation) completes a three tier petroleum system.

1. **The basal unit, comprising Pertatataka Formation shales, constitutes a proven source rock and base seal**

2. **The Arumbera Sandstone is a potential reservoir.**

3. **The Chandler salt comprises an excellent top seal.**

A number of potential leads have been mapped including an Arumbera truncation play on the margins of the Magee structure. At least two potential drill locations are possible, one of which would appraise this play plus a thickened Heavitree Quartzite section in the subthrust block. In summation, the interpretation of Arumbera Sandstone in the southern Amadeus Basin adds a third reservoir target (in addition to the Pioneer Sandstone and Heavitree Quartzite), especially where Chandler Formation salt is interpreted to form top seal. The Pertatataka shales are widespread, notably in the main depocentres and are a proven source rock.

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